

# **A simonian ontology of the artificial world**

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## **Abstract**

The first edition of *The Sciences of the Artificial* will be forty years in 2009. In this book Herbert Simon (1916-2001) gives the most complete panorama of his man-made world vision. This world can be first described as a set of artefacts, which are the things created by Humans to satisfy their needs. Simon stands that their creation is an outcome of a specific activity he calls design. Therefore the understanding of the artificial world requires moving our focus from artefacts to design. Simon adds that design is a form of problem solving. Thus, the corpus he proposes to observe and explain it can be applied to design, in order to describe the designer's bounded rationality. Moreover, Simon stands that the study of design is not an object of the natural sciences. It is an object of new sciences he calls precisely the sciences of the artificial. Despite several main results, simonian conceptualization of artificial world was not completely axiomatized. Based on an explanation of Simon's main entities (artifact, design process, problem solving, bounded rationality), this article proposes an ontology of simonian man-made world. Such a knowledge representation depicts in one single concise view this last world.

## **Keywords**

Artifact; Bounded rationality; Design; Ontology; Problem solving; Sciences of the Artificial; Simon H-A (1916-2001).

## **1. Introduction**

The first edition of *The Sciences of the Artificial* will be forty years in 2009. In all three editions of this book that succeeded in 1969, 1981, and 1997, Herbert Simon (1916-2001) gave a view as panoramic as possible of the “man-made world” (synonymous: world of the artificial, artificial world). Such purpose was first original because the words artifact, artificial, artificiality are rarely understood in a positive way (Simon, 1997) both in common sense and in philosophy (Rosset, 1973), social sciences, or even in economics. In modern societies artefacts are recognized as separate entities from natural things (Chabot, 2003), but little flattering terms are associated with them. Artefacts are usually seen as an antimony of “actual, genuine, honest, natural, real, truthful, unaffected” things (Simon, 1997). Artefacts’ definition should then be made by default: what is artificial is what it is not natural.

According to Simon, if every artifact is “fully bound by the laws of nature as any natural object” (Simon, 1995b), one should not consider it by only referring to its relation with nature. It is more relevant to analyze itself, by understanding its function and the way it was designed. Thus, artifact becomes as a label related to all things designed created by humans to satisfy their needs. Simon suggests to move our attention from the study of the artifact to those of design. Simon adds that the design is a process. Moreover, Simon sees it as a form of problem solving, so that the corpus he has developed for observing and theorizing bounded rationality can be applied in the specific case of design. Lastly, Simon concludes that the scientific study of artefacts and design requires specific empirical sciences he calls precisely the sciences of the artificial. Natural sciences aim to show how things are, whereas sciences of the artificial aim to show how things are or should be designed (Simon, 1997). These last ones need

and use specific concepts that are problematic in natural sciences, like those of function, intention, design, designer, complexity, etc.

Simon did not conceptualized artificial world in one time. Simon's reflections on artificiality and design are dotted throughout his many works, from 1960s to the late 1990s (Simon, 1969, 1981, 1992, 1995a, 1995b, 1997). Moreover, despite the panoramic landscape of artificiality he offers in *The Sciences of the Artificial*, his conceptualization of the artificial world was not based on complete axiomatic foundations. These two previous points explain the purpose of this article. Its goal is not to trace the detailed path followed by Simon in his exploration conceptualization of the man-made world, and thus following history of thought standards. On the contrary, this paper tries to make as clear as possible foundations of Simon's work, in order to propose an ontology of man-made world. In this article, an ontology is defined as "an explicit specification of a conceptualization" (Gruber, 1995). In our case that means that it is an understanding model of the man-made world.

To achieve this goal, the present paper is divided in five parts. First, it describes the world of the artificial as a set of artefacts created and used by the Man. The second part presents Simon's view of the design process as a form of problem solving. The third part details the specificities of design problem solving Simon points out, like its iterative, creative, and complex aspects. The fourth part explains how artificiality can be understood in an epistemological way, as the world studied by specific sciences, which are the sciences of the artificial. These sciences are not yet really established; despite the increasing research trend of the two last decades. The last part presents in an ontology all the quoted entities and their relationships.

## **2. Artificial world as a set of artefacts**

The simplest way to tackle man-made world is to see it as a set of artefacts. To understand the sense of this last word, we can refer to our everyday lives. Thus, one knows both what devices are and that all of them they do not exist naturally; despite they obey to limits or laws defined by the natural sciences (Simon, 1995b, 1997). In order to have a more complete view on a set of artefacts, we can add that this set take into account contains at least the following and non-trivial items mentioned by Simon:

- objects that refer to nature, like the products of the synthetic chemistry (Simon, 1995b; Simon, 1997). This kind of artefacts are copies of the nature, or natural things “produced artificially” (Searle, 2007),
- objects that not refer to nature, like a motor controller (Simon, 1997),
- production systems, like farms (Simon, 1997),
- networks, like highways (Simon, 1997),
- urban environments, like the one obtained after the renovation of Pittsburgh he mentions downtown (Simon, 1997),
- “evolving artefacts” designed on “a societal scale”, like NASA Apollo program or the Marshall plan (Simon, 1997),
- epistemic artefacts that supports the increase of our knowledge, like “techniques of simulation” (Simon, 1997),
- “physical symbol systems” designed to exhibit an intelligent behavior (Simon, 1995b; Simon, 1997).

The designers of such systems create “real intelligence artificially” and not simulate “real intelligence” (Searle, 2007). Thus, the artefacts they prototyped can be embodied

in systems that have not analogical relation with natural things, like logic programming based software applications (Simon, 1995b; Simon, 1997).

The previous list of the existing artefacts can be extended, of course. But it has no sense by itself, expected if like Encyclopaedists one wants to create an exhaustive census, typology or taxonomy of a set of artefacts (Micaëlli and Forest, 2003).

If an approach of it by extension is a first step to understand by induction what an artifact is in general, it is not sufficient. By using the word artifact, one does not designate a finite list of existing items, but a class of entities that share the same essential characteristic. For Simon, the specific characteristic of the artefacts can be expressed in the following terms: an artifact is every entity designed by humans to satisfy their needs (Simon, 1997). By the way, Simon defines artifact in intension, by using terms compliant to “functionalist postulate” (Forest and Micaëlli, 2007). Therefore, in order to understand what an artifact is, one should firstly understand: “What is it made for?”. The First attribute of the artifact is its function, and not its organic composition, its concrete body, or its evolutionary past, as in the case of the natural thing (Searle, 1999; Simon, 1995b). Its adaptation criterion is the adjustment level to a need, defined as an “external constraint” (Simon, 1995b). In consequence, the main designers’ ability consists not in producing perfect things or things that copy nature as closely as possible, but functional ones, fit to particular needs. Underscore the fact that an artifact is effectively functional if it has a set of well-defined functions and if it does not derogate from the natural laws (Simon, 1997). Whoever imagines possible to design a vehicle capable of riding, flying, floating, going under the seas or the Earth, without consuming any energy would be probably a great poet, but surely a very poor designer.

In order to achieve its function, an artifact has to exhibit an expected behavior. It must couple its “inner environment” with its “outer environment” by way of “interfaces” (Simon, 1997). An artifact can have different kinds of expected or observed behaviors, from passive ones to active or “intelligent” ones. For Simon, artifact’s behavioral abilities depend on its inner environment and interfaces (Simon, 1997). If one wants an artifact that exhibits intelligent behavior, one must embedded on it a “cognitive architecture” (Newell, Rosenbloom et al., 1989) that achieves all the functions required to exhibit this kind of behavior: pattern recognition, reasoning, memorizing, learning, etc.

By linking the artifact’s “functional requirements” (Simon, 1995b), behavior, and structure, Simon mentions the three corners of the “Function-Behavior-Structure” (FBS) triangle used in modern mechanical engineering practice and theory (Gero and Kammemgiesser, 2004). If the functionalist postulate is admitted, then the circuit along the edges of the triangle follows the sequence:

- (F) what should the expected artifact be made for?
- (B) what kind of transformations of its outer environment can it operate?
- (S) what should be its inner structure made of?

One can go around the different corners of FBS triangle by following another path. For example, some structural characteristics of an existing artifact are helpful to support new function. This idea is not speculative. It refers to what Stephen Jay Gould (1941-2002) calls “exaptation” (Jay Gould, 2002), and more precisely exaptation related to a class of artefacts the famous American paleontologist labels as “Franklins” (Jay Gould, 2002). The use of these sorts of artefacts differs radically from their usage expected by their designers. An example of Franklins is given by Simon in the first chapter of The

Sciences of the Artificial: it concerns the way sailors has used accurate chronometers for determining ships' longitude (Simon, 1997).

In Jay Gould's mind, functional exaptation is an unforeseeable and contingent phenomenon. However, for cognitive ergonomist Donald Norman, some exaptations can be anticipated and managed by the designer. This one may have the knowledge of end users' behaviors or environments, and may develop an "affordances"-based artefacts (Norman, 1988). By this way, the artifact is seen as a seed that allows users' exploratory processes. It is exactly the way of thinking of a person who designs a curriculum or a new game. Thus, the functional definition of the artifact is extended, from a narrow definition (an artifact is made for) to a wider one (an artifact is made for, but its presence in user's world also allows exaptations, and the then it gives exaptations and sometimes affordances imaginable by designer).

Conceptualization of the simonian man-made world can not be reduced to a set of artefacts defined in intention. The main idea of Simon's main idea is that the world of artefacts this set is an outcome of human's "volitional act" (Rosset, 1973), and more precisely of design (Simon, 1997). Simon adds that the core of design is the "problem solving" (Simon, 1997).

### **3. Design as problem solving**

The word design came from the Italian verb *disegno*, which means both to draw and to expect. In Simon's mind, design is a very common activity. Thus, a designer can be:

- an "instituted designer" (Forest, 2005), like the engineers who work in firms' design offices,
- a "not-still recognized" designer, like an "entrepreneur" who imagines an innovation project (Sarasvathy, 2003), a manager who creates alternative

organizational structures or practices (Boland and Collopy, 2004), or a doctor who prescribes a treatment curing a patient (Simon, 1997),

- an “everybody designer” (Bonnardel, 2006).

The modern sense of design is relatively recent. Despite the fact that design is a common and old activity, its theoretical approach is dated as early as the 1960s (Perrin, 1999; Simon, 1997). This one was largely inspired by the cybernetic thinking (Simon, 1997), and Simon is part of it when he defines design as a form of problem solving (Simon, 1995a). The harmful point is that by defining design like that, there is a risk of confusing design and choice (Simon, 1997); despite the fact that these two activities do not have the same purpose, content, horizon, and outcome. Moreover, choice or design require different abilities, skills or tools (Micaëlli and Forest, 2003; Boland and Collopy, 2004).

If design is seen as choice, then what designer does is to choose rationally a solution among existing alternatives, following well-defined criteria, and applying “substantive rationality” principles (Simon, 1976; Simon, 1978). Fortunately, in Simon’s work the confusion between design and choice is not made (Simon, 1997). For him, design and choice do not intervene at the same stage of “decision-making” (Simon, 1977). Design is an upstream stage of decision making (at least: alternatives generation), while choice is a downstream one. Said differently, the design’s function and outcome consists in creating alternatives and criteria, not choosing among these first ones. “The design attitude [...] assumes that it is difficult to design a good alternative, but once you have developed a truly great one, the decision about which alternative to select becomes trivial” (Boland and Collopy, 2004).



The other point that prevents Simon from the confusion between design and choice depends on his view of the decision-maker's rationality. Even if he is a volitional and purposeful actor, the designer is not an "omniscient and omnipotent mind" (Micaëlli and Forest, 2003). As stands the "bounded rationality" principle, he can not know both all the aspects of the need he has to satisfy, and the possible alternatives he can generate (Simon, 1967; Forest and Méhier, 2001). He has limited computational ability (Simon 1983) and attention (Simon 1995a). He must also create an artifact in a finite time (Micaëlli and Forest, 2003).

Simon characterizes bounded rationality more positively and formally by the concepts of "search" and "satisficing" (Simon, 1967). His main idea is based on the "heuristic search hypothesis", which stands that "problems are solved [...] by searching selectively (heuristically) through a problem space (i.e. a problem representation)" (Simon, 1995b). If one represents a problem with a graph, then the problem solving consists in a branch and bound process. In the case of design, such a process can be understood as follow. The designer begins with the recognition of a need for acting: create a new artifact that should satisfy a need or improve its satisfaction (Simon, 1997). The "search" for alternatives is initiated when the designer generates solutions by going from one edge of the FBS to another one. Lastly, a "stop rule" is required to end this costly cognitive process (the end of the FBS circuit). "If alternatives can not be found that satisfice, then aspiration levels will drop until an alternative is found" (Simon, 1992). That last point leads Simon to conclude that "Designing is satisficing, finding an acceptable solution" (Simon, 1995a), which is more "reasonable" or satisfactory, than optimal in the sense of the rational choice theory (Forest and Mehier, 2001). More than

acting as a usual Homo œconomicus, the simonian designer exhibits above all “the ability to produce cunning solutions to problems” (Le Moigne, 1995).

Simon’s emphasis on bounded rationality underlines the cognitive constraints the designer has to cope with, and the cognitive tactics he uses to manage them. For example, he re-uses his acquired knowledge, heuristics or analogies to generate solutions (Simon, 1997; Perrin, 1999). He also tries to simplify the current design problem by decomposing the expected artifact in modules (Simon, 1997). Thus, Simon not only defines the nature of designers’ bounded rationality, he also incidentally mentions some specificities of the design process. This last one can be characterized as iterative (Simon, 1995a), creative (Simon, Newell and Shaw, 1979), and complex (Simon, 1997).

## **4. Design specificities**

### **4.1. *Iterative design***

For Simon, design is a cyclical process that links “problem finding” or “problem forming” and “problem solving” (Simon, 1995a). The designer first tries to define the needs the expected artifact should satisfy are. He expresses the artifact’s functional requirements in terms of imperative predicates (Simon, 1997). Design problem consists in alternatives generation and choice, as shown part 2. It is stopped when a satisfying solution has been prototyped (Simon, 1997).

The reboot of the design cycle can be realized by a single designer or several successive designers. That means that the perfect artifact does not exist: it is only a provisory solution (Simon, 1997). For example, it took a half-century between the invention of canned metal box by Donkin and Hall (1810) and the can opener (1860): this first one then opening with a soldering iron!

Lastly, simonian design cycle can be potentially a perpetuum mobile. Therefore variables must be taken into account to explain how it converges. In fact, all the variables involved in the definition of bounded rationality (e.g. computational limitations, finite time, satisficing, etc.) facilitate design convergence (Micaëlli, Forest, 2003). Thus, in modern design, a shorter time is required to create new artefacts. Another variable can explain design convergence, which is the fact that design is not a simple test and trial process. The modern designer acts as a prudent man. He re-uses as much as possible existing and satisfactory way of setting problems or solutions (Visser, 1995), in order to reduce all the risks related to every design project.

#### *4.2. Creative design*

For Simon and most engineering theorists, design is also intrinsically creative (Archer, 1984; Roy, 1986; Micaëlli et Forest, 2003; Carayannis, Coleman, 2005; Bonnardel, 2006). The word creativity does not mean that designer's practice is both starting from scratch (Joas, 1996), impulsive, completely intuitive, non-rational (Joas, 1996), and therefore compliant with "some artists' poor metaphysics" (Beaune, 1998) or even mystical approaches (Sternberg and Lubart, 2005). Designers' creativity has to be understood as a "non-affective" (Deforge, 1990) and as an oriented (Chiva, Alegre, 2007) one.

In an article published in the early sixties, Simon, Newell and Shaw give some salient points of problem solving that can be applied in the case of design creativity. For these authors, creativity implies a certain kind of problem setting, an unforeseeable outcome, and empowerment attitude (tenacity, for example) (Simon, Newell and Shaw, 1962). Design creativity can be then observed and analyzed at three moments of the

design process: its beginning ( $\alpha$ -creativity), its end ( $\omega$ -creativity), and its course ( $\pi$ -creativity).

$\alpha$ -creativity — The first aspect of design creativity concerns the problem finding and forming. A design problem is usually represented by a very large list of requirements. Most of them are “ill-defined” (Simon, 1997). They are also expressed by modalities because they represent wishes or desires (Simon, 1997). Moreover, they are expressed qualitatively (e.g. a future European car has to have a certain kind of drivability) and quantitatively (e.g. it must be compliant with very strict Euro V standard) (Simon, 1992). Lastly, they are complementary (Simon, 1995a) and most of the times contradictory. The heterogeneous character of the requirements explain why designers meet problems to measure the aggregate utility of the artifact they have prototyped (Coatanéa, 2005). The interdependence between requirements explains why the synthesis of the created artifact is not trivial at all.

$\omega$ -creativity — Design creativity is also related to the outcome of the design process, that is: the artifact itself. A creative design outcome has a better value than the existing artefacts (Simon Newell and Shaw, 1962). It is also new, unpredictable, original, and even compliant with avant-gardism or counter-cultural principles or values (Bonnardel, 2006; Micaëlli and Forest, 2003). Design outcome has also epistemic effects: by designing, one knows more about the design process (Simon, 1997). Simon gives an example with the downtown Pittsburgh renovation. The outcome of this urban participative design project was not only a new downtown, but also a better understanding by the citizens involved in this project of what urban design is (Simon, 1997). Note that the produced knowledge refers not only to an object (i.e. a new

downtown) but also to a process (i.e. the participative design process). Lastly, the effect of the  $\omega$ -creativity is to modify the size and the structure of a set of the artefacts.

$\pi$ -creativity — The last aspect of design creativity is probably the most difficult to explain; despite it can be observed quite easily. It concerns the design process itself, which is recognized as oriented (Simon, 1997) but also tortuous, unpredictable (Joas, 1996), and “ill-structured” (Simon, 1977). Design process creativity can be observed in working or experimental conditions. Thus, different protocols have been created by design observers (Micaëlli, 2003), to obtain a “detailed trace” (Micaëlli and Forest, 2003) of individual (Visser, 1994) or collective (Kan and Gero, 2008) designers’ activity. One of these protocols proposed by Ericsson and Simon in the 1980s is the “think aloud, talk aloud” one (Ericsson and Simon, 1984). In the case of design, the observed designer explains what he wants to do or does, as he realizes his tasks (Visser, 1994; Visser, 1995). Usually, the design activity is observed less than an hour long, because verbalizing induces a heavy mental load (Ericsson and Simon, 1984). At the end of the session, the observer stores designer’s speech, acts and outcomes, usually called “intermediary objects” (Blanco et al., 1996) like: sketches, prototypes, notes, files, etc. (Papadimitriou and Pellegrin, 2007). Design observations show some interesting empirical results. For example, the designer usually exhibits “cognitive opportunism” (Visser, 1994). Although a final mechanical artifact can be described hierarchically as a multilevel bill of material, its design is not hierarchical. As shown cognitive psychologist Willemien Visser (1994), mechanical designers act with feedbacks if the current solution has a good or bad impact on the overall expected artifact. They also exhibit bounded rationality by reusing knowledge from a current component to another one, by delaying some local developments in order to wait to

have more data related to other modules of the artifact, etc. (Visser, 1995). The detailed trace of the design process is rather close to the interlaced lines that engraves, paints or draws Terry Winter, than to the linear processes presented in some standards.

Let us note that if everyone accepts the creative nature of the design process ( $\pi$ -creativity), there is still a harmful lack of explanation. French design theorist Armand Hatchuel proposes a theory of design (the “concept-knowledge” or C-K theory) as a process of “expansion” from the “concept” domain (e.g. functional requirements) to the “knowledge” one (e.g. possible alternatives) (Hatchuel and Le Masson, 2002). Hatchuel prefers to qualify designer’s rationality as a form of “expanded rationality” than bounded one (Hatchuel and Le Masson, 2002). If this theory can effectively describe some aspects of the  $\pi$ -creativity, one should note that it underlines a form of design reasoning, and not the rationality that occurs during such a process. Creative design still needs creative research and concepts!

#### 4.3. *Complex design*

In the eighth chapter of the last edition of *The Sciences of the Artificial*, Simon points out an important problem in modern design, which is the creation of complex artefacts following more and more complex design process (Carayannis, Coleman, 2007). Indeed, more and more artefacts contain numerous functions, behaviors or components. A car’s powertrain system satisfies hundreds of functions. It has to exhibit mechanical behaviors in several use cases: winter or summer start, use on urban road or highway, maintenance at the garage, etc. Lastly, it has more than  $10^4$  components.

In order to cope with this “functional”, behavioral, and “structural complexity” (Moles, 1972), design heuristics are required. One of them is to try to structure the expected artifact as a “nearly-decomposable system” (Simon, 1997). The main idea is

that an artifact can be represented by a matrix nowadays called by engineering theorists and practitioners “Design Structure Matrix” (DSM) (Ulrich and Eppinger, 2000).

A DSM is a square matrix that represents the connections between the components of an artifact, be its functional requirements, its functions, its sub-systems or organs, its behavior, etc. When the designer copes with a certain level of complexity, he has to imagine an architecture as modular as possible (Ethiraj and Levinthal, 2004), that is: to cluster items in order to make the design matrix as diagonal as possible (Simon, 1997). Thus, modularity is a way to solve separately problems, in order to not overload designers’ limited computational capacities (Simon, 1997). Unfortunately, real complex artefacts are rarely modular. Their designers have to focus on modules but also integrative components, which ensure the whole coherence of the artifact. These last components can be a body, a skeleton, a platform, a network, etc.

This mention of artifact’s complexity is our last presentation of the empirical aspects of Simonian man-made world. To sum up our previous words, we can say that this world exists because Humans can not satisfy all their needs with acting as pure predators, consumers or choice-makers (Micaëlli and Forest, 2003). To understand what artificial world is, it is necessary to move our focus from an outcome (a set of artefacts) to the human process which is a result (the design process, seen by Simon as a form of problem solving with iterative, creative and complex aspects). Thus, as stands Jean-Louis Le Moigne — who has disseminated Simon’s work in France (Simon, 1974) —, one can “know the rationale and the history of every artifact’s design, in spite of being constraint by hypothetic speculations about natural things: Lamarckian transformism, Darwinian evolutionism, genetics, natural selection, creationism” (Le Moigne, 1995).

As points out by this citation, the study of the artificial world induces epistemological questions.

## **5. Design as a scientific object**

For Simon, the field of scientific knowledge is divided in two parts: the sciences of the nature, and the sciences of the artificial (Simon, 1997). Their objects, epistemic communities, methods, concepts, ways of proving results, etc., differ from one another. As shows the title of *The Sciences of the Artificial*, Simon introduces a new body in this established dichotomy. Simon explains that the natural sciences show that the beauty of inanimate or living things is not incomprehensible, and can be understood by a set of concise laws empirically proved (Simon, 1997). The aim of the sciences of the artificial is to explain what an artifact is and how it is designed (Simon, 1997). Their main outcome consists of:

- specific empirical knowledge about design (e.g. detailed traces of the design process obtained following the protocol analysis observational framework),
- specific concepts, which are problematic in natural sciences (e.g. function, intention, design, designer, creativity, artifact complexity, etc.),
- tools to support designers' activity (e.g. Computer-Aided Design, design models, guidelines, creativity methods, etc.) or to learn methodically design.

To dare a very rough comparison, while the natural sciences have to explicit the laws of logic, electronics, electricity, etc., the sciences of the artificial have to explain the differences between a Macintosh and a Personal Computer. To achieve this epistemic goal, one must understand how these computers were designed: who were their designers? What was their intent? How did they develop them? But also: why and how these computers should be developed differently in the future. Such knowledge



about past and future possible design is important. It helps Humans to understand their present artificial world and to imagine a future one (Simon, 1997). Moreover, this positive and prospective knowledge is a real theoretical knowledge, not a set of practical abilities or know-how (Forest, 2005).

Simon underlines that the theoretical study of design should be a part of the curriculum of most technical studies (Simon, 1997). But engineering schools became physics or mathematics schools. Simon adds that the use of the adjective applied minimized the fact but do not change it (Simon, 1997). As underline Okudan and Zappe (2006), “both design faculty and design practitioners argue that further improvements are necessary in design teaching”. For Simon, such a harmful situation has multiples reasons: the lack of empirical knowledge on design process, the lack of recognition of academic value of these types of courses considered too intuitive, etc. (Simon, 1997). In that sense, *The Science of the Artificial* can be seen as an epistemological advocacy and agenda.

Simon announced his message in the 1960s. Unfortunately it fell for a long time on deaf ears, underlines Simon in his autobiography (Simon, 1996). After 30 years of minoration, the sciences of the artificial have today development both in their core, which is engineering, and periphery, management (Boland and Collopy, 2004) or even synthesis biology (Tessa et al., 2007), for example. The 2002 international conference on design sciences in Lyon (France) aimed at drawing up a “state of the art” of problems, scientific, methodological and practical results of such a science, and leads to the update of a research agenda for the sciences of design (Forest, 2005). For Simon, this agenda contains items related to “evaluation of designs” and design problem solving (formal aspect of design reasoning, design problems representation, etc)

(Simon, 1997). French design theorist Jacques Perrin (2005) extends this list and adds the following items:

- the genealogy of design and its conceptualization in the history of technical and scientific ideas and practices,
- the comparison between design process and scientific inquiry,
- the productive, cognitive, and linguistic content of the design process, and especially the growing role of the production or use of models and scientific knowledge in design process (Stankiewicz, 2000).

This previous list censuses outer or inner, diachronic or synchronic, past or future-oriented point of views about design. It shows the wide spectrum of the questions treated by current and future sciences of the artificial. This census ends our presentation of the empirical (artifact, design process, problem solving) and epistemological (sciences of the artificial) entities of the simonian world. Having laid this groundwork, we now propose an ontology of such a world.

## **6. Simonian ontology**

### *6.1. Ontology as a knowledge representation*

Ontology is a trap word. In philosophy, it usually defines the essence of all the things that appear in our phenomenology. Computer scientists and professionals have defined ontology in a narrower and more operative way, in order to make abstract knowledge manageable by a computer. In our case that means that an ontology is a knowledge representation and an understanding model. Its function is to depict a given reality called the simonian man-made world.

The proposed ontology tries to achieve constructive principles like “clarity”, “coherence”, and “extendibility” (Gruber, 1995). In a well-built ontology, all the entities

are reachable, there is no synonymous, and we can “plug and play” some add-on simonian entities without changing its whole coherence. If the added entity changes the sense of the proposed diagram, then it simply means that the new schema is not a simonian ontology!

In a modeling point of view, the proposed ontology is based on entities and relations. An entity can be an individual (“stop rule”, “satisficing”, “procedural rationality”) or a class (“bounded rationality”). A relation can be a membership relation (the stop rule “belongs to” bounded rationality), an event-related one (the stop rule “ends” the design process) or a property (the designer “has” bounded rationality). A relation can be also an epistemic one (the sciences of the artificial “study” the design). In the proposed ontology every relation has a direction, indicated by the symbol “>” (designer “has>” bounded rationality).

## 6.2. *The proposed ontology*

We can stand that simonian man-made world ontology contains two main classes: the design and the sciences of the artificial related by an epistemic relation. Note that if the study of a set of the artefacts is a first step to understand what man-made world is, for Simon, the entity “artifact” is not a main one. Every artifact is an outcome of the design. So, the entity “design” precedes the entity “artifact”.

The sciences of the artificial define artifact following a functionalist postulate. For them, every artifact is designed by man to satisfy his needs. Said differently, functionalism helps to discriminate an artifact to a natural thing. The sciences of the artificial also propose a systemic model of the artifact. This model contains a description of its outer environment (its functions included), inner environment, and interfaces between them (behavior included) (Fig. 1).

For Simon, the designer has a bounded rationality. He initiates a process that inherits the characteristics of problem solving. Lastly, what he does can be traced by using protocol analysis framework (Fig. 2).

Design process has also its own specificities (e.g. iterative, creative, complex aspects). Moreover, it is required when a decision-maker can not satisfy his needs by choosing among existing solutions. Design supposes a creative attitude. By giving these last points, we can propose a complete simonian artificial world ontology that links the sciences of the artificial, the problem solving, and the design (Fig. 3).

## **7. Conclusion**

Written for the 40th anniversary of the first edition of *The Sciences of the Artificial*, this article has tried to organize in a synthetic framework the work of Herbert Simon (1916-2001) related to artifact, design process, and sciences of the artificial. This paper has first presented the man-made world as a set of artefacts, defined by Simon as things designed by human to satisfy their needs (functionalist postulate). Therefore, artificiality's understanding requires moving our focus from artefacts to design process, seen by Simon as a form of problem solving that has some specificity, like an iterative, creative, and complex aspect. Moreover, Simon stands that the study of design is an object of new sciences he calls precisely "the Sciences of the Artificial". These sciences are not applied natural sciences. Their purpose is not to define the natural laws that bound artifact's function, behavior or structure, but to understand how it is designed. They use specific concepts that are problematic in natural sciences, like artifact's functions, design, complexity, designer's intent or creativity, etc.. Based on an explanation of Simon's main entities, this article lastly proposes an ontology of man-made world.

The proposed ontology refers only to Simon's approach, and not to design as it is currently observed and theorized by engineering specialists, cognitive psychologist or ergonomists, sociologists, etc. Several empirical or conceptual points can show its limitations. The first is empirical. If design supposes rational actors, what they do can be described more widely by using concepts from the "theory of activity" (Vygotski, 1962). Designers are nowadays more seen as parts of working communities (Engeström, 1987) who produce, use and share shared "intermediary objects" (Blanco et al. 1996; Papamendriou and Pellegrin, 2007). Therefore, their cognition is situated (Suwa, Gero and Purcell, 2000). It is oriented by alters or objects presented in their working situation. Moreover, the foundations of the sciences of the artificial are still weak. Exhibiting a peculiar empirical objects or censing items in an agenda is not sufficient to say that something is a science. Nowadays, the sciences of the artificial are still non-established, compared to natural, formal, or even social ones. There is no homogenous epistemic community that supports them. There are no main worldwide controversies, and the peculiar way they prove their results remains obscure. Finally, Simon's project can be seen as a first step to an empirical, conceptual, and epistemological staircase that remains to build.

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Fig. 1. The Sciences of Artificial Package.

Fig. 2 The Bounded Rationality Package.

Fig. 3. Complete Simonian Artificial World's Ontology.